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Author(s): Moody, Nathan Andrew
Tarkeshian, Roxana

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Summary of Working Group 5: Beam Sources, Monitoring, and Control

Nathan Moody
Los Alamos National Laboratory
Los Alamos, NM, USA
nmoody@lanl.gov

Roxana Tarkeshian
*Deutsches Elektronen-
Synchrotron (DESY)*
Hamburg, Germany
roxana.tarkeshian@desy.de

Abstract— This paper presents a brief summary of the contributions to Working Group 5 (WG5): Beam Sources, Monitoring, and Control. This working group was part of the 2018 Advanced Accelerator Concepts Workshop held at Breckenridge, Colorado, from August 12 to 17. There was wide-range of topics covered by this working group ranging from facility updates, new diagnostics and instrumentation schemes, new characterization methods and demonstrations (for both plasma and beam) as well as several advanced concepts that fall outside the scope of the other working groups.

I. INTRODUCTION

This working group had a total of 29 talks, 8 student posters, and 13 non-student posters. We had two joint sessions: one each with WG1 and WG8. In this working group we discussed beam sources, measurement techniques, and control techniques. The contributions were divided in the following sessions:

- Facilities overviews and diagnostics schemes
- Novel instrumentation for Laser Plasma Acceleration
- Photoemission sources
- Spatiotemporal measurement techniques
- Longitudinal beam characterization
- Transverse beam size and emittance measurements

The presentations discussed both the fundamental physics of the topics above as well as applications and demonstrations of the techniques when applicable. In the following sections we briefly review each of the topics above, using the broader categories of plasma and beam diagnostics, and emittance measurements and sources. For each, we provide a summary of the contributions and conclusions.

II. PLASMA AND BEAM DIAGNOSTICS

Mike Downer from University of Texas at Austin presented a tutorial presentation on the topic of diagnostics for plasma-based electron accelerators, emphasizing that the diagnostics in widespread use for conventional RF accelerators are insufficient for characterizing plasma-based electron accelerators. Mike Downer also presented “Single-shot movies of evolving GeV laser-plasma accelerators using multiplexed Faraday rotation” and discussed visualizing evolving GeV laser-plasma accelerator (LPA) structures in $n_e \sim 10^{17} \text{ cm}^{-3}$ plasma in a single-shot. His findings were that magnetized sheath of $50 \mu\text{m}$ plasma bubble rotates polarization of transverse $1 \mu\text{m}$, 1ps probe by ~ 1 degree; 4-frame Faraday

rotation movie shows 1) bubble formation & injection; 2) oscillation of thick sheath in rear of bubble due to mismatched drive pulse focus; and 3) thinner steady-state sheath in center of bubble after several cm propagation. Remaining challenges: Fully resolve evolving bubble sheath thickness; visualize bubble evolution in beam-driven GeV PWFAs.

J. R. Welch, UT Austin, presented “Brookhaven ATF experiment AE-71: CO₂ laser-driven wakefields” and discussed generation and visualization (plasma density and field structure) of Mid-IR LWFA, reporting a first demonstration of nonlinear self-modulated plasma wakes driven by mid-IR laser pulses ($\lambda=10.6 \mu\text{m}$, 4ps, 0.5TW). Remaining challenges: 3D density and field visualization in SM (ATF I) and blowout regimes (ATF II) + external injection.

J. van Tilborg, BELLA Center, LBNL, presented on “Active plasma lenses (APLs) as high-gradient transport element,” and discussed the advantages and concerns of APLs, tailored to various applications, reporting that non-linear B(r) can be mitigated with small beams. An analytic expression for wakefield degradation was presented, highlighting the strong advantages of APLs. Remaining challenges: Design optimum APL configuration, improve linearity.

J. van Tilborg, BELLA Center, LBNL, also presented on “Density characterization of discharged capillaries through common-path spectral-domain interferometry,” outlining and demonstrating an upgrade from two-path spectral-domain two-color interferometry to common-path; Remaining challenge: Measure phase velocity & demonstrate $<10^{15} \text{ cm}^{-3}$ sensitivity.

C.V. Pieronek, BELLA Center, LBNL, presented “Group velocity measurements in laser-heated capillary discharge waveguides for laser-plasma accelerators,” discussing characterization of laser-heated capillary discharge waveguides for petawatt LPAs and reporting that laser-heating can bring waveguide parameters close to requirements for acceleration to 10 GeV. Remaining challenges: Further optimize laser-heating to reach ultimate goal of 10 GeV beam production.

Yong Ma, from Centre for Ultrafast Optical Science, University of Michigan, presented “Adaptive control of relativistic electron beams from wakefields driven by 150 GW Mid-IR laser pulses in near-critical-density plasma,” discussing the challenge of coherent control of the parameter space of LWFA. Optimization of the electron beam qualities

from LWFA drive by Mid-IR laser was reported by controlling the laser wavefront via a genetic algorithm. Remaining challenges: coherent control of laser beam spatial and temporal characteristics simultaneously.

Alex Lumpkin, FermiLab, presented on “Observations of COTR Interference Fringes Generated by Laser-driven Plasma Accelerator Electron Beamlets,” discussing the development of single-shot, noninvasive, high resolution electron beam diagnostics and showed the first sub-micron emittance estimates of microbunched electrons from LPA using COTR-based techniques. Remaining challenges: refine and extend interferometry to energy assessment of microbunched beamlets and to GeV scale.

Maxwell LaBerge, UT Austin, presented “Laser Wakefield Electron Bunch Spatial Reconstruction Through Coherent Transition Radiation Imaging,” discussing methods to diagnose the LWFA electron bunch size and structure just outside the accelerator structure. Significant microbunching was observed in the visible region due to beamlets in the electron bunch, and approximately 1 mm outside the plasma, these beamlets have a few micron transverse size. Remaining challenges: combine information from CTR spectrometer and COTR images to produce a full 3D reconstruction of the electron bunch.

Alexander Debus presented “From LWFA bunch durations to bunch profile and micro-structure,” discussing ways to measure longitudinal bunch profiles of ultrashort, bright LWFA beams at single-shot. Spectral CTR techniques (UV-MIR, 200nm-12 μ m) were successfully applied to systematically measure LWFA electron bunch profiles. Remaining challenges: 3D-bunch distribution reconstruction by combining CTR spectrum & COTR imaging data.

Andrew Sutherland, SLAC National Accelerator Laboratory, presented “Plasma-photonic diagnostic of relativistic electron and laser beams,” discussing temporal and spatial synchronization of laser pulses with electron bunches in advanced accelerator experiments and applications, demonstrating the capability for 15 fs timing and 5 μ m spatial accuracy at the interaction point. Remaining challenges: identifying the scaling laws and how these could be lead to further improving accuracy.

Renkai Li, also from SLAC National Accelerator Laboratory, presented “THz-based sub-femtosecond metrology of bright electron beams,” discussing methods of controlling bright electron beams with femtosecond accuracy and beyond, concluding that the laser-generated THz field can clock bright relativistic electron beams with sub-fs precision but challenges remain in THz control and metrology at attosecond level, as well as application to external injection for laser accelerators.

Dao Xiang, Shanghai Jiao Tong University, presented a related talk on “Few-femtosecond Electron Beam with Wakefield-driven Compression,” discussing ways to compress an electron beam without introducing timing jitter and concluded that the wakefield by a drive beam can be used to compress a witness beam without introducing timing jitter.

Remaining challenge: Integrate this passive buncher with PWFA.

III. EMITTANCE MEASUREMENTS AND SOURCES

S. K. Barber, Lawrence Berkeley National Laboratory, presented “Emittance measurements of laser plasma accelerated electron beams for advanced accelerator applications,” discussing single-shot, emittance diagnostic methods with sub micron resolution, implemented for LPA source characterization. It was reported that emittance depended upon the injection mechanism, with the down-ramp method producing 2x smaller emittance than ionization injection. With modest improvements in beam quality, SASE FEL gain was described as achievable for the BELLA center FEL project.

Paul Winkler, DESY, presented “Emittance Measurements at LUX,” focusing on implementation of a reliable single shot emittance diagnostic for LWFA beams and finding that the demonstrated beam stability at LUX enables scans with significant statistics; future improvement in higher resolution is needed to measure the smallest emittances anticipated.

Lianmin Zheng, Argonne National Laboratory, presented “Emittance Correction in a transversely coupled photoinjector with quad corrector,” discussing a new methods to suppress emittance growth due to coupled aberrations in the photoinjector and showed that a quad corrector can indeed used but requires rapid optimization of the quad parameters in real applications.

Levi Schachter Technion, Israel Institute of Technology, presented, “Guiding an Electron-Beam with an Optical Bessel-Beam,” discussing a theoretical method for eliminating electromagnetic guidance of an electron beam by using the optical field instead. Preliminary theoretical analysis indicates that an Optical Bessel Beam (1 μ m) may guide electrons over distances of several meters with conserved emittance of less than 100pm.

David Bruhwiler, RadiaSoft LLC, presented “Semi-analytic calculation of Magnetized Dynamic Friction and Relevance to IOTA,” discussing the cooling of relativistic hadrons for a future electron-ion collider (EiC) and reporting a new dynamical friction force obtained analytically for a constant velocity electron distribution. Remaining challenges: integrate over thermal electron distribution and propose experimental tests for the IOTA ring at Fermilab.that validate this approach.

Anusorn Lueangaramwong¹, Northern Illinois University, presented “Design and Commissioning of a low energy DC gun for fieldemission cathode investigation,” discussing another approach toward nano-tip field-emitter cathodes using etched silicon. Simulations validating the design of the DC gun were reported and nano-tip geometries in fabrication and current-voltage were presented with experimental results. Remaining challenges: identifying a design methodology for selecting tip geometry and composition based on electron beam requirements.

Chengkun Huang, Los Alamos National Laboratory, presented “Emission models and beam dynamics for diamond emitters in a compact source of high brightness beams,” discussing detailed emission physics of micron- to nano-scale emitters for high brightness compact sources, showing (1) diamond emission properties can be derived from a physical model; and (2) high brightness beams are emitted from emission small area. Remaining challenges: (1) photo excitation for bulk diamond and nano-scale structure; (2) integrated modeling and validation.

Vitaly Pavlenko, Los Alamos National Laboratory, presented “Studies of the Field Assisted Photoemission from Nanocrystalline Diamond and Diamond Field Emitter Arrays,” discussing applicability of diamond field emitters as laser-triggered electron sources for DLAs. Experimental results showed enhanced photoemission from relatively dense DFEAs vs flat nanocrystalline diamond. Remaining challenges: studies needed on the limits of maximum photoemission current.

Jiahang Shao, Argonne National Laboratory, presented “Recent upgrade and commissioning of the Argonne Cathode Test-stand (ACT),” discussing in-situ high resolution field emission imaging. Testing of advanced cathodes was shown in real gun environment, with strong field emission (FE) from pre-defined emitters observed with a maximum local field of 10 GV/m. Remaining challenges: improving resolution and study of FE evolution during cathode characterization.

IV. SUMMARY

In summary, rapid advances were reported in the performance of accelerator and beam/wakefield instrumentation and new schemes for electron emission and emittance measurement were presented. Plasma accelerator research has driven innovation in electron bunch diagnostics: 1) measurement of normalized transverse emittance $\epsilon_n < 0.1$ mm mrad and bunch duration $\tau_b \sim 1$ fs is realistic noninvasively in one shot; 2) plasma structure diagnostics: visualization of plasma and electric field profiles of evolving, μ m-scale plasma accelerators noninvasively in one shot; 3) CTR/COTR based techniques are being deployed for 3D charge density reconstruction. Remaining challenges include: single-shot, noninvasive, high resolution recovery of 6D plasma-accelerated bunch profiles; single-shot 4D visualization of plasma accelerator structures; and development of synthetic diagnostics. Additionally, minimally invasive methods, such as ionization based techniques, will come to the forefront and could enable active tuning and feedback control of advanced accelerators that enable new performance regimes.

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